The Influence of Catalytic and Dry Low NOx Combustor Turbulence on Vane and Endwall Heat Transfer

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Motivation

The gas turbine industry has responded to the stringent emission requirements in areas of heavy population with the development of low emission combustion systems. These systems use lean premixed combustion processes to lower combustor temperature levels and reduce the formation of thermal NOx. These systems include dry low NOx (DLN) and catalytic combustors. While these combustors enhance the environmental impact of gas turbine power, they also pose both a risk and a possible opportunity to turbine developers due to changes in the turbulence levels and temperature patterns entering first stage turbine nozzles.

High levels of turbulence generated in combustion systems have been found to augment heat transfer in laminar regions of vanes and to promote early transition. Additionally, combustor turbulence has been found to hasten dissipation of film cooling protection. In DLN as well as aeroderivative and industrial combustion systems, combustion is sustained in regions of large-scale recirculation. These recirculation regions are also responsible for producing high levels of large-scale turbulence that persists into the first stage vane. A recent study by Van Fossen and Bunker (2000) measured turbulence levels of 28 percent at the exit of an ambient DLN combustor. This result suggests that, depending on the combustor configuration, DLN combustors could produce turbulence levels even higher than more conventional combustors.

Unlike DLN and more conventional combustion systems, catalytic combustors sustain combustion on their catalytic surfaces. Catalytic combustion systems need a high surface to flow area, which equates to tiny passages. Consequently, catalytic combustors can be expected to produce a small-scale turbulence that dissipates rapidly. This indicates that compared to more conventional systems catalytic combustor turbulence may reduce augmentation, delay transition, and allow film cooling to be more persistent. As a result, *turbine designers may be able to take advantage of catalytic combustion systems by reducing cooling requirements for and the complexity of first stage vanes.*

Objectives

The purpose of this research is to investigate the characteristics of turbulence generated by DLN and catalytic combustion systems and determine its impact on vane and endwall heat transfer and endwall film cooling. Additionally, in order to take advantage of the lower turbulence levels generated by catalytic combustors a second cascade with a aft loaded vane has been designed and is nearly completed. This cascade will also feature endwall contouring to reduce the influence of secondary flows. This contoured endwall cascade will highlight the effects of inlet contouring and aft loading on vane and endwall heat transfer and endwall film cooling. Additionally, the database developed using these two geometries will enable the grounding of advanced CFD models for vane and endwall heat transfer and film cooling.

Vane Heat Transfer Results. Vane midline heat transfer distributions were acquired over a four to one range in Reynolds numbers for the six turbulence conditions. Stanton number distributions for an exit chord Reynolds number of 2,000,000 based on true chord are shown in figure 6 along with predictions. Distance from the stagnation region along the pressure surface is given by negative surface condition, while the suction surface is denoted by positive surface distance. Stanton numbers are based on average exit conditions. The six turbulence conditions appear to generate three separate behaviors. On the pressure surface the DLN and AC conditions shown laminar augmentation levels up to 100% before transition begins around a surface distance of –0.2 m. The grid and ACS conditions show an augmentation level of over 60% with transition occurring shortly after the higher turbulence cases. Finally, the low turbulence and CC conditions show no transition and only a moderate level of augmentation. In the stagnation region (0.0 m) augmentation levels of up to 50% are seen and are ordered similar to the pressure surface. On the suction surface, transition is initiated near the minimum pressure point for the four highest turbulence levels. The catalytic combustor turbulence causes transition to start at a surface distance of 0.35 m but never reach fully turbulent flow. The average midline heat transfer level for the DLN combustor is 2.2 times the level of the mock catalytic combustor for exit Reynolds numbers of 2,000,000 and 1,000,000 and 1.8 times the level for the 500,000 Reynolds number case.

The STAN7 finite difference boundary layer predictions use the predicted pressure distributions and the measured inlet turbulence characteristics adjusted for the short decay length between the measuring plane and the vane leading edge. The eddy diffusivity due to external turbulence is calculated using the ATM model of Ames, Kwon, and Moffat (1999). The code also uses the transition model of Mayle (1991). Overall the predictions are very good as the ATM model captures the laminar augmentation well and the Mayle model provides a good estimate of transition onset and length. However, the Mayle model is conservative in predicting transition on the suction surface.

Conclusions

The most significant finding of this research to date is the verification of the relatively low turbulence levels generated by catalytic combustion systems and the corresponding decrease in vane surface heat transfer. This research is expected to produce a well-resolved database for the grounding of advanced computational models for vane and endwall heat transfer prediction.

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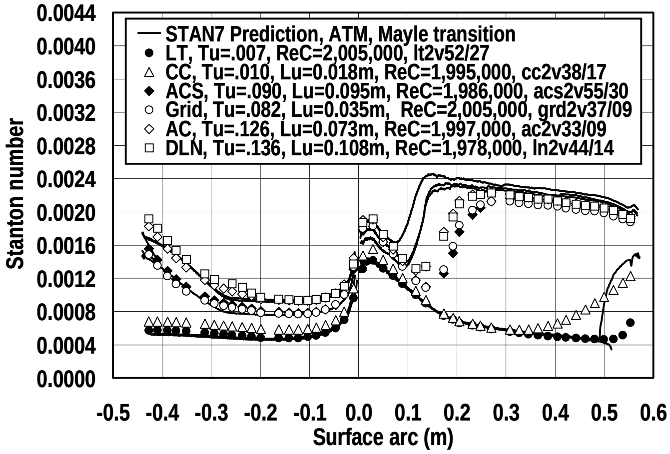
STAN7 Prediction, ATM, Mayle transition
LT, Tu=.007, ReC=2,005,000, lt2v52/27
CC, Tu=.010, Lu=0.018m, ReC=1,995,000, cc2v38/17
ACS, Tu=.090, Lu=0.095m, ReC=1,986,000, acs2v55/30
Grid, Tu=.082, Lu=0.035m, ReC=2,005,000, grd2v37/09
AC, Tu=.126, Lu=0.073m, ReC=1,997,000, ac2v33/09
DLN, Tu=.136, Lu=0.108m, ReC=1,978,000, ln2v44/14
Stanton number
Surface arc (m)
0.0044
0.0040
0.0036
0.0032
0.0028
0.0024
0.0020
0.0016
0.0012
0.0008
0.0004
0.0000
-0.5
-0.4
-0.3
-0.2
-0.1
0.0
0.1
0.2
0.3
0.4
0.5
0.6